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Preoperative radiological indicators for prediction of difficult laryngoscopy in patients with atlantoaxial dislocation

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ABSTRACT

Background: Difficult airway remains a great challenge in patients with atlantoaxial dislocation (AAD). Preoperative evaluation and reliable prediction are required to facilitate the airway management. We aimed to screen out reliable radiological indicators for prediction of difficult laryngoscopy in patients with AAD.
Methods: A retrospective nested case-control study within a single center longitudinal AAD cohort was conducted to investigate the radiological indicators. All the patients with difficult laryngoscopy from 2010 to 2021 were enrolled as the difficult laryngoscopy group. Others in the cohort without difficult laryngoscopy were randomly selected as the non-difficult laryngoscopy group by individually matching with the same gender, same surgery year, and similar age (±5 years) at a ratio of 6:1. Radiological data on preoperative lateral X-ray images between the two groups were compared. Bivariate logistic regression model was applied to screen out the independent predictive indicators and calculate the odds ratios of indicators associated with difficult laryngoscopy. Receiver operating characteristic curve and area under the curve (AUC) were used to describe the discrimination ability of indicators.
Results: A total of 154 patients were finally analyzed in this study. Twenty-two patients with difficult laryngoscopy and matched with 132 controls. Four radiological parameters showed significant difference between the two groups. Among which, ΔC1C2D (the difference of the distance between atlas and axis in the neutral and extension position), owned the largest AUC.
Conclusions: ΔC1C2D could be a valuable radiologic predictor for difficult laryngoscopy in patients with AAD.

1. Introduction

Difficult airway remains a great challenge in clinical practice. Failure in difficult airway management can lead to severe

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complications such as airway injury, teeth injury, unnecessary tracheotomy, brain injury, respiratory and cardiac arrest, and even death. The proportion of difficult endotracheal intubation reported can be as high as 20.0 %–30.2 % in patients with cervical spine disease [1,2]. A preliminary study of Peking University Third Hospital (PUTH) showed that the proportion of difficult airway in elective cervical surgery was 17.1 % [3].

The upper cervical spine, also known as atlantoaxial segment, mainly includes occipital condyle, atlas (C1) and axis (C2). The occipito-atlantal and atlantoaxial articulations provide 50 % of the flexion and rotation in the cervical spine, respectively [4,5]. Atlantoaxial dislocation (AAD) is a common disease in the craniocervical junction area, which can be caused by factors such as inflammation, tumors, trauma, and congenital malformations [6]. The clinical symptoms of AAD include symptoms related to cervical radiculopathy, high cervical myelopathy caused by compression of the medulla oblongata junction, respiratory dysfunction, etc. [7], which can progress to incomplete limb paralysis, and even respiratory failure. X-ray is the first choice for diagnosing AAD, with the measurement of atlantodental interval (ADI). Under normal circumstances, the ADI is a narrow small gap that does not exceed 3 mm in adults and 5 mm in children [8,9]. Patients with AAD often have concurrent bony deformities, instability, and ligamentous laxity [10]. As a result, patients with AAD are at a greater risk of difficult airway. Preoperative evaluation and reliable prediction are required to facilitate the airway management.

Some studies showed that preoperative radiological images can be used to predict difficult endotracheal intubation during anesthesia [1–3]. However, it is found that in clinical practice these prediction methods are not completely applicable to patients undergoing atlantoaxial surgery, which may be caused by the anatomical and functional particularity of the upper cervical spine. After literature search, there is little objective imaging predictor of difficult laryngoscopy for such patients. Considering that the atlantoaxial disease is a rare disease with low incidence, and the sample size is limited, we conducted a nested case-control study based on an AAD cohort, which can scientifically and objectively analyze the imaging predictors of difficult laryngoscopy of atlantoaxial patients on the premise of limited sample size. So far as we know, this might be the first cohort study using radiological indicators to predict difficult airways in AAD patients with a larger sample size. Several radiological indicators were screened to filter out independent prediction indicators. Our findings could provide valuable information for airway management in AAD patients, decrease mortality and morbidity, and improve the prognosis and outcome of these patients.

2. Materials and methods

2.1. Study population

Patients who underwent upper cervical spine (atlantoaxial and cervical occipital fixation) surgery in PUTH from January 1st, 2010 to December 31st, 2021 were selected. Inclusion criteria were as follows: (1) AAD; (2) age < 65 years old; (3) BMI < 30 kg/m^2. Exclusion criteria were as follows: (1) with airway tumor of space occupying lesions; (2) American Society of Anesthesiologists (ASA)

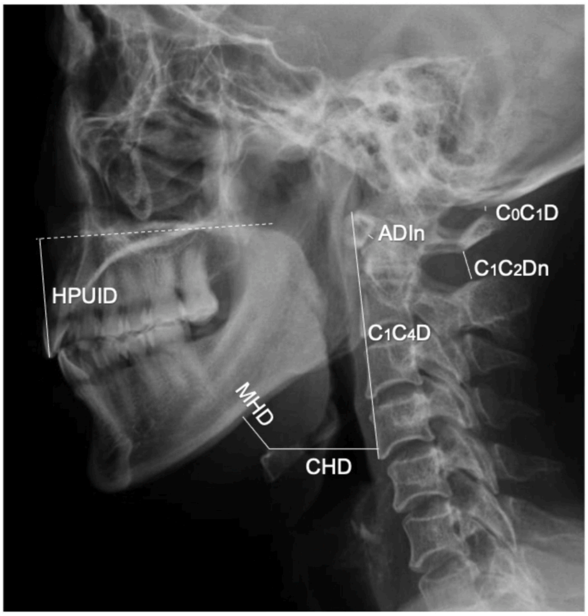

Fig. 1. Parameters measured on preoperative lateral X-ray images in the neutral position. HPUID, perpendicular distance from hard plate to the tip of upper incisor; MHD, distance from mandibular body to hyoid bone; CHD, horizontal distance from the border of the nearest cervical vertebra to the highest point of hyoid bone; C1C4D, distance from the upper edge of C1 to the lower edge of C4; C0C1D, distance between the occipital bone and the atlas; C1C2Dn, distance between the atlas and the axis and ADIn (the atlantodental interval), horizontal distance between the anterior arch of the atlas and the dens of the axis.

physical status IV or V; (3) anticipated difficult mask ventilation. The radiological data were retrieved on the Picture Archiving and Communication Systems (PACS).

2.2. Grouping

Medical charts and anesthesia records were obtained from the hospital medical data system and retrospective nested case-control study was designed. Since videoscopes are not widely available and convenient in early years, the Macintosh laryngoscope was initially used for visualization during the first attempt. Difficult laryngoscopy was defined according to the structures visualized and identified by Macintosh laryngoscopy by an experienced anesthesiologist. The Cormack-Lehane (*C*-L) grading system was applied to define difficult (grade III or IV) group in the cohort [11]. Subsequently, tracheal intubation was carried out using either the Macintosh laryngoscope or advanced airway devices, such as video laryngoscopes, fiber-optic bronchoscopes (FOB), or Shikani optical stylets. For patients with difficult airways, intubation was performed according to ASA guidelines. Patients without difficult laryngoscopy were randomly selected as the non-difficult laryngoscopy group by individually matching with the same gender, same surgery year, and similar age (±5 years) at a ratio of 6:1.

2.3. Variables

X-ray examination was performed with standing position. Radiological data were obtained mainly on lateral projection images. All X-ray data were evaluated using radiography information system (Centricity RIS-IC CE V3.0; GE Healthcare, Little Chalfont, UK) of the PUTH. Distance and angle indicators were measured in neutral and extension position. All imaging measurements were completed by the same radiologist. The radiologist was blinded to group allocation and was not involved in the airway management.

The indicators measured in neutral position were as follows (Fig. 1): perpendicular distance from hard palate to the tip of upper incisor (HPUID), distance from mandibular body to hyoid bone (MHD), horizontal distance from the border of the nearest cervical vertebra to the highest point of hyoid bone (CHD), distance from the upper edge of C1 to the lower edge of C4 (C1C4D), distance between the occipital bone and the atlas (C0C1D), distance between the atlas and the axis (C1C2Dn) and horizontal distance between the anterior arch of the atlas and the dens of the axis (the atlantodental interval, ADIn) [12].

The indicators we measured in extension position were distance between the atlas and the axis (C1C2De) and ADIe, shown in Fig. 2. The difference between C1C2Dn and C1C2De were calculated and recorded as ΔC1C2D. The difference between ADIn and ADIe were calculated and recorded as ΔADI.

Angles measured on preoperative lateral X-ray images in the neutral position were shown in Fig. 3. Angle A is the angle between the line parallel to the hard palate (line1) and the line connecting the anterior edge of C1 and C2 (line2); angle B is the angle between line1 and the line connecting the cricoid cartilage and the midpoint of the airway (line3); angle C is the angle between the McGregor's line (line4, connecting the posterior edge the hard palate and most caudal point of the occipital curve) and the inferior end plate of C2 (line5); angle D is the angle between line5 and the inferior end plate of C6 (line6). These angles were also measured in extension

Fig. 2. Parameters measured on preoperative lateral X-ray images in the extension position. C1C2De, distance between the atlas and the axis and ADIe (the atlantodental interval), horizontal distance between the anterior arch of the atlas and the dens of the axis.

position, and the difference between these positions were recorded as ΔAngle A, B, C, D (°).

The number of fixed segments (NOFS) from craniovertebral junction (C0–C1) to C6–C7 was evaluated with preoperative cervical computed tomography (CT) and X-ray images by the same experienced orthopedist, who was also blinded to group allocation and not involved in the airway management.

2.4. Statistical analysis

Continuous variables were summarized using mean ± standard deviation ($\overline{x}$ ± SD) for normally distributed data and median with interquartile range (IQRs) for non-normal distribution. Difference between the two groups in continuous variables were analyzed using either independent samples *t*-test (normal distribution) or Mann-Whitney *U* test (non-normal distribution). Categorical variables were analyzed using the Chi-square test. A Binary logistic regression model was applied to identify multivariate predictors, with odds ratio (OR) and 95 % confidence interval (95 % CI) used to indicate the strength of association. The receiver operating characteristic (ROC) curve was used to evaluate the discriminatory ability of the predictive indicators. The area under the curve (AUC) was used as a quantitative index. The Youden's index (= sensitivity + specificity - 1) was calculated, and the highest score was the optimal predictive cut-off value. SPSS version 22 statistical software (SPSS, Inc., Chicago, IL) was used for data statistical analysis. $P < 0.05$ was defined statistically significant.

According to the principle that the number of events per variable, that is, the number of outcome events corresponding to each independent factor is not less than 5. In the logistics model with difficult laryngoscopy as the outcome event, three independent variables were considered. Twenty-two patients with difficult laryngoscopy and 132 patients with non-difficult laryngoscopy were included to meet the sample size criterion.

3. Results

3.1. Characteristics of participants

There were a total of 2260 patients underwent upper cervical spine surgery during 2010–2021. And 1160 met the inclusion criteria. Among them, there were 32 patients with difficult laryngoscopy were recorded in the hospital medical data system. A total of 10 patients were excluded because of incomplete radiological data. Others in the cohort without difficult laryngoscopy were randomly selected as the control group by individually matching with the same gender, surgery year (±1 month), and similar age (±5 years) at a ratio of 6:1. Finally, there were 22 patients selected as the difficult laryngoscopy group and 132 patients as the non-difficult laryngoscopy group (Fig. 4). General demographic information of the participants was shown in Table 1. There was no significant difference

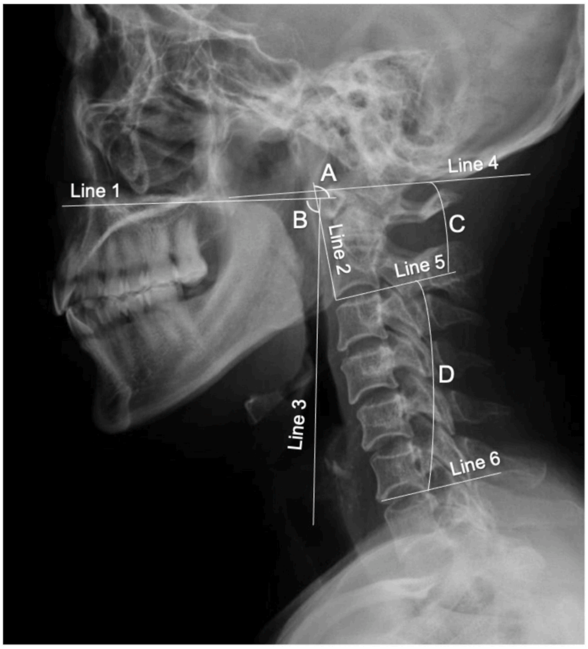

Fig. 3. Angles measured on preoperative lateral X-ray images in neutral position. Angle A: the angle between the line parallel to the hard palate (line1) and the line connecting the anterior edge of C1 and C2 (line2); angle B: the angle between line1 and the line connecting the cricoid cartilage and the midpoint of the airway (line3); angle C: the angle between the McGregor's line (line4, connecting the posterior edge the hard palate and most caudal point of the occipital curve) and the inferior end plate of C2 (line5); angle D: the angle between line5 and the inferior end plate of C6 (line6).

in gender, age, height, weight, BMI, and ASA classification between the two groups (P > 0.05).

3.2. Airway management and recovery outcomes

Eight patients (36.4 %) in the difficult laryngoscopy group were operated with occipitocervical fixation (OCF) technique previously. Among all patients with difficult laryngoscopy, 19 patients (86.4 %) were successfully intubated with different alternative techniques. Seven patients were intubated via fibreoptic bronchoscope (FOB), 4 patients via Shikani optical stylet，and 8 patients via video laryngoscope (VL). Two patients (9.1 %) failed intubation after attempts but can be rescued with effective face mask ventilation (one of the patients did not undergo surgery, and the other underwent awake FOB intubation and receive surgery 8 days later). Emergent tracheotomy was performed in one patient (4.5 %). The patient was a 42-year-old woman suffered with the hardware failure after previous occiputaxial fixation and was prepared for revision surgery. Due to the three segments fixed in the previous operation, the range of motion of craniovertebral junction was severely limited. After intravenous propofol 80 mg was administered, VL was performed for the first time, and the epiglottis was not visible. A nasopharyngeal airway was performed to assist ventilation and maintain oxygenation. Intubation via FOB failed after several attempts. In the end, the emergent tracheotomy was performed successfully by the otolaryngologist [Fig. 5(a-h)].

After the surgery, 21 patients (95.5 %) were transferred to general ward, 1 patient (4.5 %) with endotracheal intubation was transferred to intensive care unit (ICU), and tracheotomy was performed 6 days later. None of the patients died of airway complications.

3.3. Association between mobility indicators and outcomes

The relevant parameters indicating cervical mobility were shown in Table 2. Four of the indicators showed significant differences: C1C2Dn (P = 0.039), ΔC1C2D (P < 0.001), ΔAngle A (°) (P = 0.010), and NOFS (P < 0.001). There were no statistical differences in other parameters (P > 0.05).

Binary multivariate logistic regression (backward Wald) analyses identified three independent correlative factors from all the cervical mobility indicators that correlated best as predictors of difficult laryngoscopy: Δ C1C2D (mm), ΔAngle A (°) and NOFS. The odds ratio (OR) and 95 % CI of these indicators were 1.449(1.042–2.014), 1.119(1.029–1.215) and 0.568 (0.342–0.944), respectively (Table 4).

The AUC and standard error calculated for C1C2Dn, ΔC1C2D, ΔAngle A and NOFS are shown in Table 3. We used the ROC curve and AUC to assess the predictive abilities of these predictors. Δ C1C2D has the largest AUC (0.766; 95 % CI 0.653–0.878). Area under the curve of C1C2Dn was 0.638 (95 % CI 0.512–0.763).

The Youden's index (sensitivity + specificity - 1) was applied to define an optimal cut-off value which take both sensitivity and specificity into account. According to the highest Youden's index, the cut-off value of ΔC1C2D was set to 1.95, with the sensitivity and specificity was 0.645 and 0.842, respectively. In clinical scenario, false negative of a screening tool may lead to disaster consequence since difficult intubation cannot be alerted. Thus, we prefer a cut-off value with a higher sensitivity of 0.796, corresponding cut-off value is 1.05 with a specificity of 0.632 and a Youden's index of 0.428. The highest specificity is 0.842 when the cut-off value is

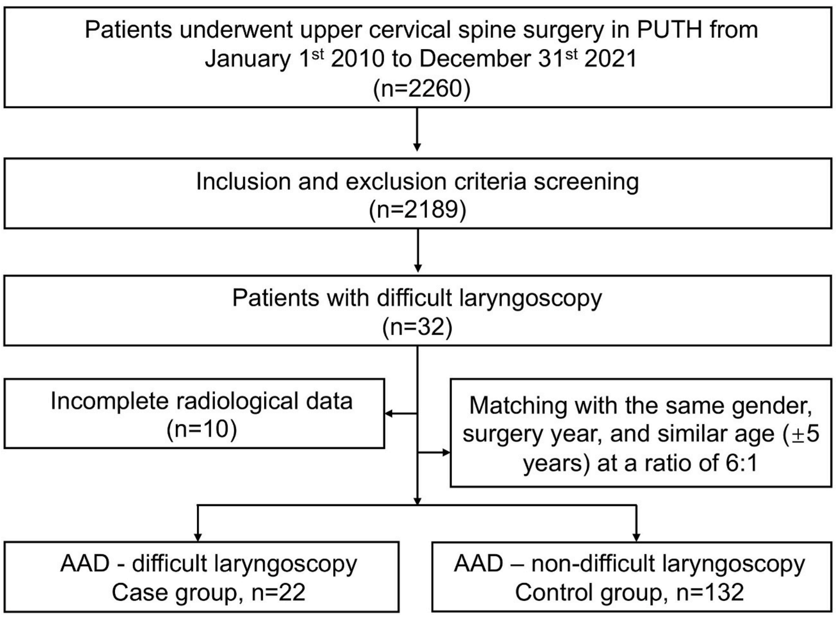

Fig. 4. Flow diagram outlining the selection of the study population. AAD, atlantoaxial dislocation.

Table 1
Demographics of the difficult and non-difficult laryngoscopy groups.

Items	Non-difficult laryngoscopy Group (n = 132)	Difficult laryngoscopy Group (n = 22)	Statistical Test	*P* values
Gender(n)			0.000	1.000
Male	66	11		
Female	66	11		
Age (yr)	48 (11)	50 (11)	−0.237	0.813
Height (cm)	160.5 ± 10.5	162.1 ± 7.7	−0.864	0.389
Weight (kg)	61.7 ± 11.3	60.6 ± 16.7	−0.245	0.808
BMI (kg/m^2)	23.4 (3.9)	23.65 (6.7)	−0.419	0.675
ASA classification			1.925	0.165
I	63	7		
II	69	15		

Values are presented as the number of patients or median (IQR) or mean ± SD, BMI: Body mass index, ASA: American Society of Anesthesiologists.

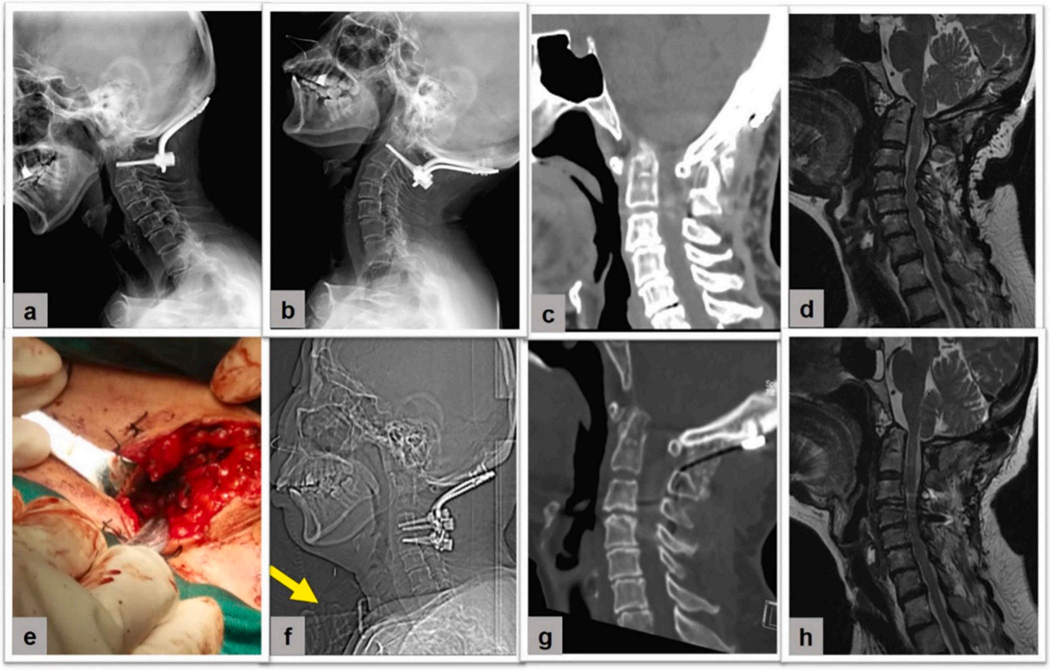

Fig. 5. Perioperative radiological images and tracheotomy field photo of a 42-year-old woman of difficult laryngoscopy group who underwent emergent tracheotomy. The number of fixed segments (NOFS) was 3 and ΔC1C2D was 1.21 mm. a&b: Preoperative dynamic X-ray showed previous occiput-C2 fixation failure and limited ROM of craniovertebral junction; c: Preoperative CT scan revealed recurrent atlantoaxial dislocation and odontoid protruding upward to the fossa; d: Ventral medullary compression can be found from preoperative MRI; e: Emergent tracheotomy was performed; f: The revision procedure included posterior reduction and occiput-C4 fixation and fusion, and tracheotomy tube (yellow arrow) can be found in the postoperative radiography; g: Postoperative CT scan revealed the odontoid was pulled down and complete atlantoaxial reduction; h: Fully medullary decompression was confirmed by postoperative MRI.

1.95, and the sensitivity is 64.5 % (Table 5).

4. Discussion

Difficult airway is still a great threat to perioperative patient safety in anesthesia practice. Incidence of difficult laryngoscopy is higher in patients undergoing atlantoaxial surgery due to unique anatomical characteristics. Besides, methods used to predict difficult airway in cervical spine surgery are not applicable in AAD. Our cohort-based nested case control study provides novel indicators that can predict difficult laryngoscopy in AAD patients. Radiological images should be considered in preoperative evaluation of airway to reduce morbidity and mortality. To the best of our knowledge, this study represents a pioneering cohort study utilizing radiological indicators for predicting difficult airways in patients with AAD. Given the relatively low incidence rate of AAD, our study stands as the largest cohort study conducted thus far in this field.

Previous studies have focused airway management mainly in the lower cervical spine surgery [1–3]. There is limited literature available on the anesthesia management of atlantoaxial dislocation, with only a few case reports addressing this topic [13]. While the

Table 2
Cervical mobility indicators to predict difficult laryngoscopy between the two groups of patients undergoing upper cervical spine surgery.

Items	Non-difficult laryngoscopy group (n = 132)	Difficult laryngoscopy group (*n* = 22)	Statistical Test	*P*-values
HPUID (mm)	28.8 (7.9)	29.3 (4.0)	−0.292	0.770
MHD (mm)	12.0 (12.0)	13.7 (10.4)	−0.605	0.545
CHD (mm)	37.4 (8.1)	35.4 (8.2)	0.977	0.329
C1C4D (mm)	77.7 ± 11.3	76.1 ± 11.1	−0.594	0.553
C0C1D (mm)	4.0 (3.50)	3.0 (4.79)	1.008	0.313
Angle An (°)	101.6 (19.2)	104.5 (15.1)	−1.117	0.264
Angle Ae (°)	103.6 ± 15.3	102.5 ± 14.5	−0.270	0.787
ΔAngle A (°)	**2.1(8.7)**	**−1.6(15.9)**	**2.587**	**0.010**
Angle Bn (°)	86.1 (13.5)	90.8 (13.6)	−1.003	0.316
Angle Be (°)	102.0 (15.3)	96.6 (21.2)	1.325	0.185
ΔAngle B (°)	15.0 (12.8)	8.0 (13.0)	1.903	0.057
Angle Cn (°)	9.3 (12.0)	9.4 (15.2)	0.023	0.981
Angle Ce (°)	18.3 (18.8)	11.4 (24.7)	1.196	0.232
ΔAngle C (°)	6.6 (16.0)	3.6 (4.3)	0.996	0.319
Angle Dn (°)	15.1 (14.6)	20.8 (26.7)	−1.080	0.280
Angle De (°)	31.5 ± 13.7	32.8 ± 18.1	0.351	0.726
ΔAngle D (°)	14.6 ± 11.0	11.0 ± 9.3	−1.269	0.207
C_1C_2Dn (mm)	**8.9(8.3)**	**5.6(7.3)**	**2.604**	**0.039**
C_1C_2De (mm)	3.8 (7.1)	3.7 (10.7)	−0.141	0.887
Δ C_1C_2D (mm)	**3.2(4.7)**	**0.9(1.4)**	**3.625**	**< 0.001**
ADIn (mm)	5.7 (5.1)	5.0 (3.7)	0.983	0.326
ADIe (mm)	3.6 (5.3)	5.3 (4.3)	−0.727	0.467
ΔADI (mm)	1.6 ± 2.37	0.7 ± 2.2	−1.267	0.208
NOFS	**0.0(1.0)**	**2.0(3.25)**	**−3.839**	**< 0.001**

Values are presented as median (IQR) or mean ± SD, HPUID: perpendicular distance from hard plate to the tip of upper incisor, MHD: distance from mandibular body to hyoid bone, CHD: horizontal distance from the border of the nearest cervical vertebra to the highest point of hyoid bone, C1C4D: distance from the upper edge of C1 to the lower edge of C4, C0C1D: distance between the occipital bone and the atlas, C1C2Dn: distance between the atlas and the axis in neutral position, ADIn: the atlantodental interval in neutral position, C1C2De: distance between the atlas and the axis in extension position, ADIe: the atlantodental interval in extension position, ΔC1C2D: difference between C1C2Dn and C1C2De, ΔADI: difference between ADIn and ADIe, Angle A: angle between the line parallel to the hard palate (line1)and the line connecting the anterior edge of C1 and C2 (line2), Angle B: angle between line1 and the line connecting the cricoid cartilage and the midpoint of the airway (line3), Angle C: angle between the McGregor's line (line4, connecting the posterior edge the hard palate and most caudal point of the occipital curve) and the inferior end plate of C2 (line5), Angle D: angle between line5 and the inferior end plate of C6 (line6), Angle n: angle in neutral position, Angle e: angle in extension position,ΔAngle: difference between Angle n and Angle e, NOFS: number of fixed segments.

Table 3
Predictive values of cervical mobility indicators for predicting difficult laryngoscopy.

Indicators	AUC	95 % CI	SE	*P*-value
ΔAngle A	0.700	0.563–0.837	0.070	0.010
C1C2Dn	0.638	0.512–0.763	0.064	0.039
NOFS	0.731	0.604–0.858	0.065	0.001
Δ C_1C_2D	0.766	0.653–0.878	0.057	<0.001

ΔAngle A: difference between Angle An and Angle Ae, C1C2Dn: distance between the atlas and the axis in neutral position, NOFS: number of fixed segments, Δ C_1C_2D: difference between C1C2Dn and C1C2De, AUC: area under the curve, 95%CI: 95 % confidence interval, SE: standard error.

Table 4
Cervical mobility predictors for difficult laryngoscopy identified by binary multivariate logistic regression (backward-Wald) model.

Variable	B	SE	*P*-value	OR	95 % CI
ΔAngle A	0.112	0.042	0.008	1.119	1.029–1.215
Δ C1C2D	0.371	0.168	0.027	1.449	1.042–2.014
NOFS	−0.565	0.259	0.029	0.568	0.342–0.944
Constant	1.392	0.564	0.014	4.024	

SE, standard error; OR, odds ratio; 95%CI, 95 % confidence interval; ΔAngle A: difference between Angle An and Angle Ae; ΔC1C2D: difference between C1C2Dn and C1C2De; NOFS: number of fixed segments.

incidence of atlantoaxial disease is low, the amount of the patients is numerous. Over 2000 patients underwent upper spine surgery during the past 11 years in our single center. This cohort provides solid support to our study and made one of our major strengths. Many patients with AAD have a history of other syndromes like Trisomy 21, Grisel syndrome, and Mucopolysaccharidosis, etc [13–17]. Undefined airway description may pose challenges to the anesthesiologists and increase the risks associated with tracheal intubation.

Classical physical evaluation indicators such as modified Mallampati test, interincisal gap, thyromental distance, neck mobility,

Table 5
Calculated cut-off values for ΔC1C2D.

Cut-off point	Sensitivity	Specificity	Youden's index
1.95	0.645	0.842	0.487
1.05	0.796	0.632	0.428
1.75	0.677	0.789	0.466
1.8	0.667	0.789	0.456
1.65	0.688	0.737	0.425
1.7	0.677	0.737	0.414
1.15	0.774	0.632	0.406
1.35	0.72	0.684	0.404
1.2	0.763	0.632	0.395

ΔC1C2D: difference between C1C2Dn and C1C2De.

and upper-lip-bite test, combined with radiological indicators like X-ray and ultrasound were widely used and investigated [18–20]. In our previous study involving 270 patients undergoing cervical surgery, we identified several indicators from X-ray images to be potentially effective predictors for difficult airway in cervical spine surgery. Our study showed that, parameters showed significantly relevant in lower cervical spine surgery were not applicable in AAD patients. None of C1C2Dn and C1C2De were independent correlative factors in lower cervical spine surgery. The results confirmed that AAD patients are special in cervical spine surgery population and should be spliced as a unique subpopulation.

Δ C1C2D referred to the difference between C1C2Dn and C1C2De, along with ΔAngle A and NOFS, indirectly reflect the upper cervical mobility in neutral and extension positions. Numerous studies on reduced neck mobility have been conducted to investigate whether it is useful for prediction of difficult airways [21]. Cervical spine mobility is included in the Wilson score, a useful scoring system for difficult airway prediction, which was analyzed by Roth et al. [19]. Mashour et al. reviewed 14,053 pa-tients and found that the incidence of difficult laryngoscopy is associated with limitation of cervical spine mobility [21]. The cervical mobility limitation in patients with atlantoaxial diseases is mainly limited to the upper cervical spine, which has its anatomical and physiological particularity. The occipito-atlantal and atlantoaxial articulations provide 50 % of the flexion and rotation in the cervical spine, respectively [5]. Sawin and Horton reported that during laryngoscopy, most of the cervical motion is produced at the atlantooccipital and atlantoaxial joints and that the subaxial cervical segments (C4 and below) are displaced only minimally [22,23]. Some previous studies have aimed static indicators [24], while our research has dynamically evaluated the range of motion of the upper cervical spine. Δ C1C2D accounts for the majority of craniocervical movement in patients with AAD. Calder et al. found that mouth opening and craniocervical movement are interrelated. Humans achieve full mouth opening by extending approximately 26° from the neutral position [25]. Patients with restricted craniocervical movement may have reduced mouth opening ability, which can directly affect laryngoscope maneuvers. Impaired mouth opening and atlantoaxial mobility may contribute to the difficulties with airway management that can occur in difficult laryngoscopy patients with AAD. In this study, C1C2Dn was significantly lower in the difficult laryngoscopy group [5.6 (7.3) vs, 8.9 (8.3), $P = 0.039$], ΔC1C2D was one of the three independent correlative factors from all the cervical mobility indicators that correlated best as predictors of difficult laryngoscopy, with the largest AUC (0.766; 95 % CI 0.653–0.878). These results confirmed that in AAD patients, mobility remains to be an important predictor.

Occipito(O)–C2 angle has been widely measured to assess cervical lordosis in the occipital-C2 region. Matsubayashi et al. reported that there was an inverse correlation between the *O*–C2 angle, and the C2–C7 angle after an OCF [26]. This compensatory mechanism to some extent explains the high incidence of difficult laryngoscopy in patients post-OCF. However, *O*–C2 angle (angle C) showed no statistical significance between the two groups in this study. According to previous studies, *O*–C2 articulation only contribute 15–25 % to the total flexion -extension range of motion of the neck [27]. Thus, *O*–C2 angle may not be that important from orthopedic perspective when under intubation prediction circumstance.

As we all know, neck of the AAD must be strictly kept inline immobilization to avoid secondary injury of spinal cord [28]. Thus, preoperative screening of X-ray images for difficult airway assessment in AAD patients could be carried out as a surrogate or supplementary of bedside evaluation of upper cervical mobility.

New indicators like the occiput and external acoustic meatus to axis has been shown to be valuable in predicting dysphagia in patients suffering from anterior atlantoaxial subluxation after occipitocervical fusion [29,30]. Although the surgery type is different, the difficult airway may share similar mechanisms. Further study may be designed to investigate the prediction abilities of these indicators.

In recent years, technological advancements have provided new insights in the field of airway management. Videolaryngoscopy has become increasingly utilized in clinical practice, and grading systems such as the Video Classification of Intubation (VCI) score have been developed and are currently being validated [31]. Virtual laryngoscopy, a non-invasive radiological technique, offers a valuable simulation tool for perioperative management of patients with obstructive upper airway lesions. Further investigation is needed to determine the potential benefits of using these techniques for intubation in patients with AAD [32].

Our study has several limitations. The sample size is limited due to the low incidence of AAD. Since our hospital is one of the largest AAD centers in the country, we designed a nested case control study to obtain reliable results. In addition, X-ray imaging is readily available preoperatively and can be conveniently measured using PACS. Therefore, our study primarily focused on the evaluation using X-ray imaging. However, it is important to note that CT and MRI imaging were not included within the scope of our study and should be further investigated in future research.

In Conclusion, Δ C1C2D based on preoperative X-ray images could be valuable radiologic predictor of cervical mobility indicators for difficult laryngoscopy in patients with AAD.

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Data availability statement

The data underlying this article are available in [Mendeley Data Repository], at https://data.mendeley.com/datasets/s982nntx9d/1.

Ethics statement :

This study was approved by Medical Scientific Research Ethics Committee of Peking University Third Hospital.
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Participants consent statement

The participants have consent to have these images published.

Additional information

No additional information is available for this paper.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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